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SATELLITE BROADCASTING: slant path attenuation through rain storms

J.L. Eaton, B.Sc., M.I.E.E.

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SLANT PATH ATTENUATION THROUGH RAIN STORMS
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Summary

A recently proposed statistical precipitation rate profile for isolated rain storms in the U.K. is employed to obtain the effective attenuation path length or 'effective distance' for storms lying directly in the transmission path from a broadcasting satellite operating in the 12 GHz band. This effective slant-path distance is a function of the elevation angle and distance from the storm centre. The greatest precipitation rate occurs at the centre of the storm. The attenuation rate (dB/km) corresponding to uniform rainfall at this maximal precipitation rate, when multiplied by the effective distance, yields the excess path attenuation due to the storm. The results represent the greatest attenuation to be expected in 85% of all rain storms.

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1. Introduction

A factor that must be taken into account when planning satellite broadcasting services in the 12 GHz band is the signal attenuation due to intense rainfall. Existing studies, mostly related to satellite links rather than broadcasting, have assumed uniform extensive rainfall from a given height above ground. At 12 GHz, intense rainfall is the only appreciable risk to a satellite broadcast service which in Northern Europe and in the UK in particular, tends to be due to isolated storms moving with the wind. The worst situation arises when the storm centre passes directly over the point of reception along the transmission path. An improved rainfall model is needed for Northern Europe if realistic predictions of rainfall attenuation statistics are to be made. Harden, Norbury and White have recently proposed empirically derived intensity/distances profiles for intense convective rainfall.¹ An application of their results leads to an improved model for prediction purposes.

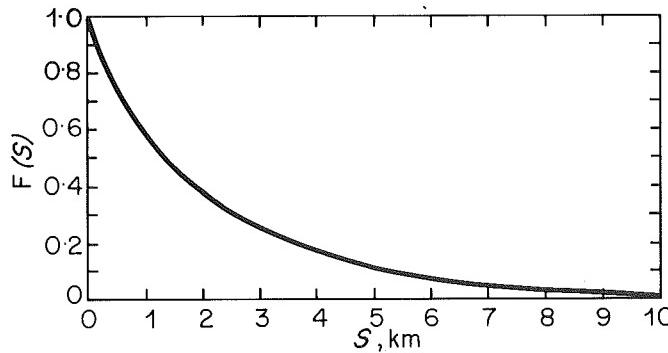
2. Attenuation rate

From CCIR Report 233-2² it is found that rainfall attenuation can be expressed in the form $\gamma = KR^\alpha$ dB/km. when K and α are constants and R is the precipitation rate in mm/hr.

Fitting the values for γ at 12 GHz from Figure 3(a) of Report 233-3 yields $K = 0.014$ and $\alpha = 1.248$. These values of the parameters give an attenuation with precipitation rate curve which agrees closely with the stated values.

3. The intensity/distances profile

Based on their rainfall measurements Harden, Norbury and White present three intensity/distances profiles for heavy convective rainfall. These represent the mean values of their observations and mean values plus and minus one standard deviation respectively. In planning studies it is important to consider worst case results; therefore the expression for mean plus one standard deviation will be used in the following calculations. This is expressed in terms of a circularly symmetrical distribution function.



$$F(S) = 0.17Z^7 + 0.83Z$$

$$\text{where } Z = \exp(-0.38S)$$

and S = radial distance in km from the point of peak intensity (storm centre).

$F(S)$ is the fractional value from the peak intensity. The function is shown in Fig. 1. It is clear that individual storm distributions will not follow this profile. It is equivalent to the profile within which 85% of all profiles lie. In the following it will be taken to represent a model storm so that the results obtained correspond to a worst case for 85% of all storms. In real situations the storm may move with the wind for significant periods of time without much alteration in the distribution pattern.

4. Effective distance

Assuming a transmission path passing through the model storm centre and using the distribution function of Fig. 1, an effective distance can be found. Initially it is useful to consider a horizontal path that would be typical of terrestrial point-to-point links. The effective distance D_T is the distance through uniform rainfall of the peak intensity that yields the same total attenuation. It should be obvious that the effective distance is independent of the peak intensity value. Because of symmetry it is convenient to consider first the effective distance D from the point of peak intensity along a finite path of length S' .

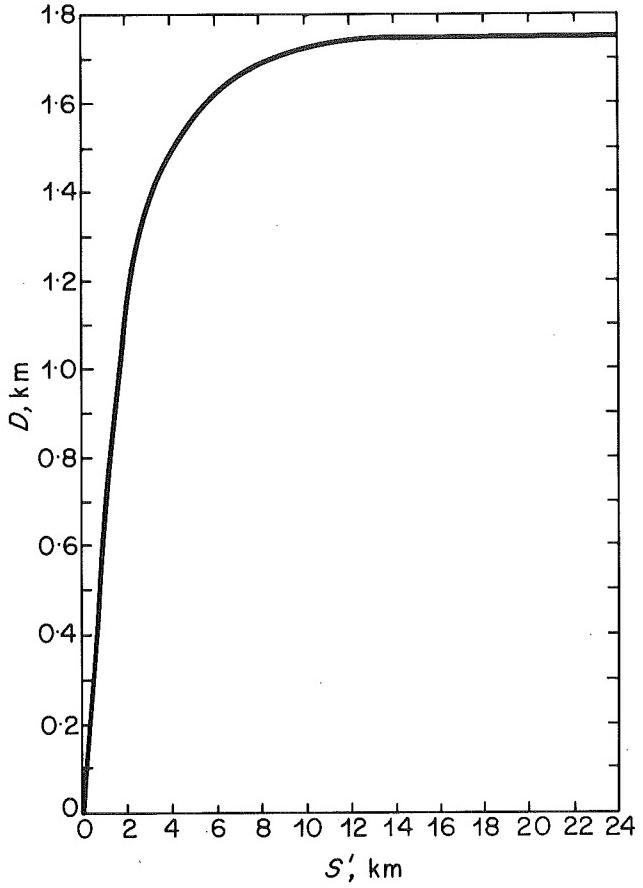
Then the attenuation over the path on one side of the point of peak intensity is:

$$A(S') = K \int_0^{S'} [R_{\text{peak}} F(S)]^\alpha dS$$

$$= K (R_{\text{peak}})^\alpha \int_0^{S'} [F(S)]^\alpha dS$$

Fig. 1 - Rainfall rate distribution (relative)

Fig. 2 - Effective distance from point of peak intensity



and the effective distance is

$$D(S') = \int_0^{S'} [F(S)]^\alpha dS$$

The integral may be readily evaluated (see Appendix) and $D(S')$ for $\alpha = 1.248$ is shown in Fig. 2.

5. Effective distance on a slant path

On a slant path with elevation angle θ , the situation can

be dealt with by scaling the abscissa of Fig. 1 with the multiplying factor $\sec \theta$. On the slant path the distribution function therefore becomes:

$$F(S_\theta) = F(S \cdot \sec \theta)$$

where S_θ is the slant path distance.

The effective distance on the slant path is:

$$D(S'_\theta) = \int_0^{S'_\theta} [F(S_\theta)]^\alpha dS_\theta = \sec \theta \int_0^{S'} [F(S \cdot \sec \theta)]^\alpha dS = D'(S')$$

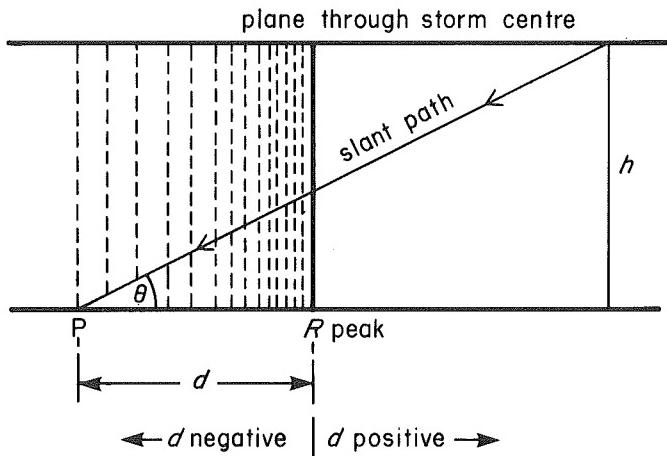


Fig. 3 - Slant path model

Putting $Z = \exp(-0.38 \cdot \text{Sec}\theta \cdot S)$ this integral may be evaluated as before.

6. Slant path model

A diagram of the slant-path model is shown in Fig. 3. This represents vertical rainfall to a constant height (h) with the horizontal distribution about R_{peak} as given in Section 3. P is the position of a satellite broadcast receiver and d_g is the slant-path distance in a plane through the storm centre at elevation angle θ . The distance (d) of P , along the ground from R_{peak} is made negative to indicate that the slant path passes through the storm centre and positive otherwise.

The total effective slant-path distance taking into account attenuation on both sides of R_{peak} is then

$$D_T = eD'(|d|) + gD'(|\cot\theta + d|)$$

$$\text{where } e = \begin{cases} +1, & d < 0 \\ -1, & d > 0 \end{cases}$$

$$g = \begin{cases} -1, & (h\cot\theta + d) < 0 \\ +1, & (h\cot\theta + d) > 0 \end{cases}$$

and D' is defined in Section 5.

Fig. 4 shows plots of effective slant-path distance D_T relative to peak rainfall intensity through the storm centre in terms of the distance of the reception point from the storm centre with the angle of elevation as a parameter. The height of the rainfall is assumed to be 3 km.

7. Discussion

7.1. In the foregoing the analysis has been derived from a model in which a rain storm centre lies directly on

slant path. Modified intensity profiles could be derived to model the cases when the storm centre lies to one side of the path.

7.2. Taking for example, a peak precipitation value of 50 mm/hr the curves of Fig. 4 can be transformed into attenuation functions. The maximal attenuations are given in the Table.

θ degrees	Max. Atten. dB	Distance from storm centre km
0	6.4	20 (and greater)
10	6.0	8.5
20	5.1	4.0
30	4.1	2.5
40	3.2	1.8

7.3. For a convective storm passing across the transmission path the curves of Fig. 4 can be used to give the greatest attenuation that will occur. Knowledge of the distance of the storm centre from the receiver along the transmission path and the rain intensity at the centre is required.

7.4. The model will be most reliable at the lower angles of elevation because of the, at present, unknown rain intensity distributions at high levels. Furthermore, a region of melting snow flakes exists above most storms and additional attenuation should perhaps be included to account for this. (When a snow flake melts it forms a wet surface and appears like a very large water drop.) Further study is required on these points.

8. Conclusions

When considering the quality of service that will be provided by a broadcasting satellite to domestic viewers a safety margin must be added to the required signal power flux to allow for rainfall attenuation.

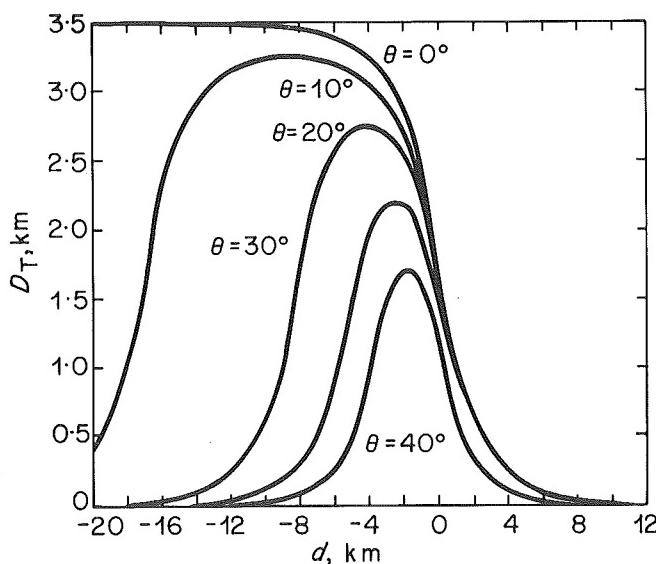


Fig. 4 - Effective slant path distance

For terrestrial services in other bands it is often useful to predict that a given signal strength will be exceeded for a large percentage of the time (99.9% say). Such a prediction can be relevant when the fading pattern is expected to result mostly in short periods of low signal strength. The argument put forward in this report is that, for satellite broadcasting in the 12 GHz band, the most serious source of excess signal attenuation will be convective rainstorms passing across the transmission path close to receiving installations. This being the case, low signal conditions may persist for relatively long periods, possibly up to half an hour in duration. Further work is needed to assess the consequences of this contention.

As a first step, it is necessary to have a method for estimating rainstorm attenuation with reasonable accuracy. A method is presented in the foregoing sections. A more formidable task will be to combine this method with measured statistics and meteorological data to predict the incidence and duration probability of signal fades. This information seems to be important if we are to be able to

evaluate the continuity of satellite broadcasting services in the future.

9. Acknowledgement

Valuable comments on the draft text by Dr. J.R. Norbury of the Appleton Laboratory are gratefully acknowledged.

10. References

1. HARDEN, N.B., NORBURY, J.R. and WHITE, W.J.K. Model of intense convective rain cells for estimating attenuation on terrestrial millimetric radio links. *Electronic Letters*, 1974, **10**, pp. 483 – 484.
2. CCIR XIIth Plenary Assembly (Geneva, 1974) Vol. V. Report 233-3, Section 4.3.

11. Appendix

Effective distance D(km)

$$= \int_0^{S'} [F(S)]^\alpha dS$$

$$\text{where } F(S) = 0.17Z^7 + 0.83Z$$

$$Z = \exp(-0.38S)$$

$$[F(S)]^\alpha = (0.83Z)^\alpha (1 + 0.205Z^6)^\alpha$$

$$= (0.83Z)^\alpha \sum_{j=0}^{\infty} \binom{\alpha}{j} (0.205Z^6)^j$$

$$= (0.83)^\alpha \sum_{j=0}^{\infty} \binom{\alpha}{j} (0.205)^j Z^{(6j+\alpha)}$$

$$\begin{aligned} \int_0^{S'} Z^{(6j+\alpha)} dS &= \int_0^{S'} \exp[-0.38(6j+\alpha)S] \\ &= \frac{1}{0.38(6j+\alpha)} \left\{ 1 - \exp[-0.38(6j+\alpha)S'] \right\} \end{aligned}$$

$$D = \frac{(0.83)^\alpha}{0.38} \sum_{j=0}^{\infty} \binom{\alpha}{j} \frac{(0.205)^j}{(6j+\alpha)} \left\{ 1 - \exp[-0.38(6j+\alpha)S'] \right\}$$

The series converges rapidly.

